

**Rb-Sr AND Sm-Nd AGES, AND PETROGENESIS OF DEPLETED SHERGOTTITE NORTHWEST AFRICA 5990.** C.-Y. Shih<sup>1</sup>, L. E. Nyquist<sup>2</sup>, Y. Reese<sup>3</sup>, and A. J. Irving<sup>4</sup> <sup>1</sup>Mail Code JE-23, ESCG/Jacobs Sverdrup, P.O. Box 58477, Houston, TX 77258-8477, chi-yu.shih-1@nasa.gov; <sup>2</sup>Mail Code KR, NASA Johnson Space Center, Houston, TX 77058-3696, laurence.e.nyquist@nasa.gov; <sup>3</sup>Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX 77058, young.reese-1@nasa.gov; <sup>4</sup>Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195, irving@ess.washington.edu.

**Introduction:** Northwest Africa (NWA) 5990 is a very fresh Martian meteorite recently found on Hamada du Draa, Morocco and was classified as an olivine-bearing diabasic igneous rock related to depleted shergottites [1]. The study of [1] also showed that NWA 5990 resembles QUE 94201 in chemical, textural and isotopic aspects, except QUE 94201 contains no olivine. The depleted shergottites are characterized by REE patterns that are highly depleted in LREE, older Sm-Nd ages of 327-575 Ma and highly LREE-depleted sources with  $\epsilon_{Nd} = +35 \sim +48$  [2-7]. Age-dating these samples by Sm-Nd and Rb-Sr methods is very challenging because they have been strongly shocked and contain very low abundances of light rare earth elements (Sm and Nd), Rb and Sr. In addition, terrestrial contaminants which are commonly present in desert meteorites will compromise the equilibrium of isotopic systems. Since NWA 5990 is a very fresh meteorite, it probably has not been subject to significant desert weathering and thus is a good sample for isotopic studies. In this report, we present Rb-Sr and Sm-Nd isotopic results for NWA 5990, discuss the correlation of the determined ages with those of other depleted shergottites, especially QUE 94201, and discuss the petrogenesis of depleted shergottites.

**Samples and Analytical Procedures:** A large chip of NWA 5990, weighing ~1.1 g was allocated for this study. After chipping out fusion crusts, the sample was crushed gently to pass a nylon sieve of opening size <149  $\mu\text{m}$ . About 238 mg was taken as the bulk rock sample (WR). The rest of the sample was sieved into 74-149  $\mu\text{m}$  (335 mg) and 44-74  $\mu\text{m}$  (205 mg) size fractions. Mineral samples were separated from the 74-149  $\mu\text{m}$  size fraction. The non-magnetic plagioclase (Plag) and the most magnetic opaques (MM) were separated by a Franz magnetic separator at current 1.0 A. The pyroxene and olivine samples were separated from the magnetic portion of the sample by densities using heavy liquids. In the density fraction (3.32-3.55  $\text{g/cm}^3$ ), we obtained the pyroxene sample (Px). In the density heavier than 3.55  $\text{g/cm}^3$ , we separated the olivine sample (Ol). In addition, the bulk rock and all mineral samples were washed with HCl (1N for Plag, MM and Ol and 2N for WR and Px) in an ultrasonic bath for 10 minutes to eliminate possible post-crystallization, extra- or terrestrial, contamination. Residues (r) of acid-washed bulk rock and mineral samples, WR leaches (l)

and the combined acid washes from all minerals (Leach) were analyzed.

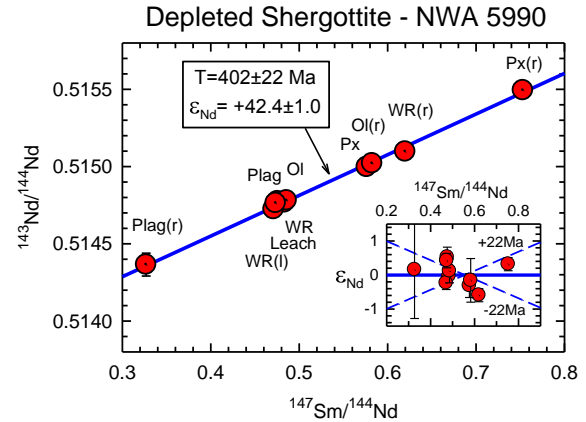


Figure 1. Sm-Nd isochron of NWA 5990.

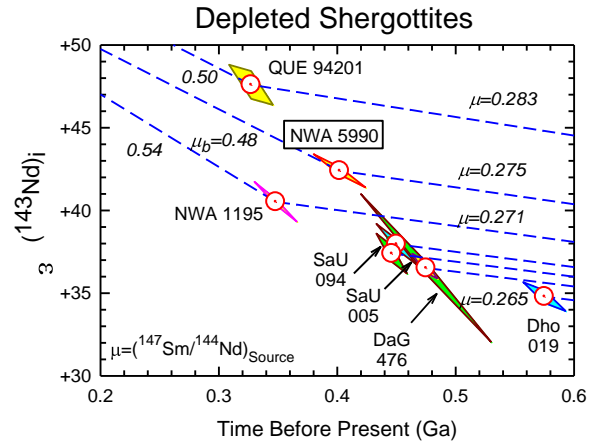


Figure 2.  $\epsilon_{Nd}$  vs.  $T(\text{age})$  of Depleted Shergottites.

**Sm-Nd isotopic results:** Fig. 1 shows  $^{147}\text{Sm}/^{144}\text{Nd}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  data of ten NWA 5990 samples (red circles). All ten data points define a good linear array corresponding to a Sm-Nd age of  $402 \pm 22$  Ma for  $\lambda(^{147}\text{Sm}) = 0.00654 \text{ Ga}^{-1}$  and an initial  $\epsilon_{Nd} = +42.4 \pm 1.0$ , using the Isoplot regression routines [9]. This age is older than those of QUE 94201 ( $327 \pm 19$  Ma [2]) and NWA 1195 ( $347 \pm 13$  Ma [7]), but younger than those of SaU 094/005 ( $445 \pm 18$  Ma [6]), DaG/Y98 ( $470 \pm 12$  Ma [4,5]) and Dho 019 ( $575 \pm 18$  Ma [3]). Initial  $\epsilon_{Nd}$  and age data for seven depleted shergottites studied so far are summarized in Fig. 2. It clearly shows that at least five igneous events related to the formation of depleted shergottites are identified. The magmatic activities spanned ~250 Ma. Variable exposure ages for these

meteorites suggest that they came from at least four impact-ejection events.

**Rb-Sr isotopic results:** The  $^{87}\text{Rb}/^{86}\text{Sr}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  data for ten NWA 5990 samples (red circles) are shown in Fig 3. Unlike the Sm-Nd isotopic system in Fig 1, the Rb-Sr isotopic data are scattered and are not in isotopic equilibrium. However, four acid washed mineral samples (red solid circles) composed of two plagioclase (Plag and Plag(r)), pyroxene (Px(r)) and opaques (MM(r)) are collinear yielding an age of  $389 \pm 12 \text{ Ma}$  for  $\lambda(^{87}\text{Rb}) = 0.01402 \text{ Ga}^{-1}$ , which is within error of the corresponding Sm-Nd isochron age. The corresponding initial  $^{87}\text{Sr}/^{86}\text{Sr}$  is  $0.701497 \pm 9$ .

**Petrogenetic implications:** Using a two-stage model, the mantle sources of these shergottites are implied to have super-chondritic  $^{147}\text{Sm}/^{144}\text{Nd}$  of  $\sim 0.26$ – $0.28$ . These high values suggest they were derived from strongly LREE-depleted mantle sources. To produce even more LREE-depleted melts of  $^{147}\text{Sm}/^{144}\text{Nd} \sim 0.5$  found in depleted shergottites by partial melting event(s) at 327–575 Ma is not straightforward. It could have involved multiple episodes of remelting of residues at 327 Ma, as suggested for the genesis of depleted shergottite QUE 94201 [2].

Alternatively, these depleted shergottites (DS) could have been produced by processes with three major stages, as shown in Fig. 4. This model starts with the formation of a DS source precursor at  $\sim 4.553 \text{ Ga}$ , soon after martian core formation, and while the short-lived nuclides  $^{146}\text{Sm}$  (most) and  $^{182}\text{Hf}$  (some) were still alive [10–13]. This source precursor could have been a garnet-bearing peridotitic cumulate crystallized during the early martian mantle differentiation. The model cumulate had nakhlite-like  $^{147}\text{Sm}/^{144}\text{Nd} = \sim 0.235$ , but un-nakhlite-like low  $^{87}\text{Rb}/^{86}\text{Sr} = \sim 0.04$ . It evolved until  $\sim 1 \text{ Ga}$ , when partial melting produced nakhlite-like LREE-enriched melts (red thin dotted lines) and their corresponding highly LREE-depleted residues. These residues became the direct DS sources, from which DS finally were produced by large degree melting 327–575 Ma ago. This three-stage model can also explain the nakhlite-like positive  $^{142}\text{Nd}$  anomalies ( $\sim +0.6 \epsilon$ ) of DS [e.g. 11, 13]. The Sm and Nd abundances of DS Yamato 980459 were reproduced by this model in [5].

The above model suggests that we should have more martian meteorites of the Hesperian era, corresponding to LREE-enriched nakhlite-like melts produced between  $\sim 925 \text{ Ma}$  and  $\sim 1.38 \text{ Ga}$ , and associated with the production of DS sources. The ages of these mafic to permafic magmas (open red circles in Fig 5), although so far not sampled, would support the wide distribution of Hesperian volcanic materials on the martian surface implied by the revised crater-frequency curve of [14].

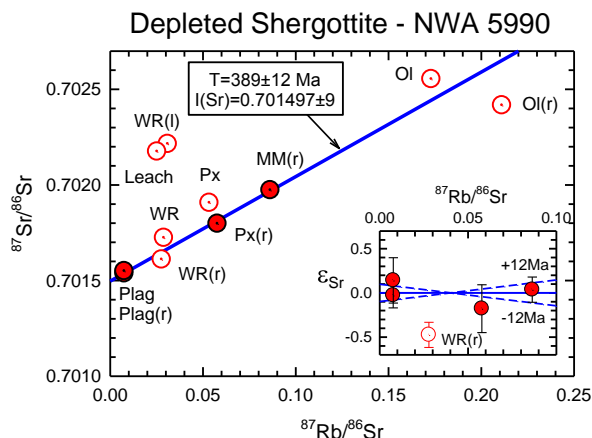


Figure 3. Rb-Sr isochron of NWA 5990.

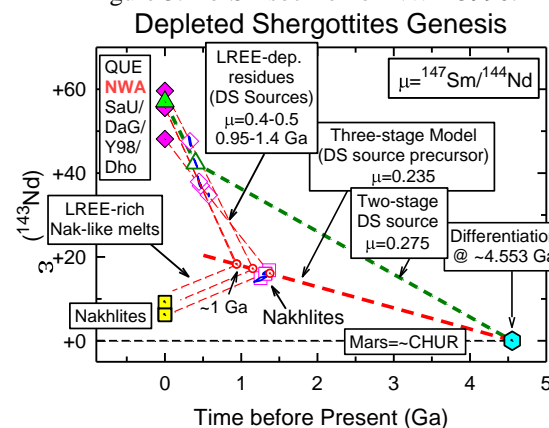


Figure 4.  $\epsilon_{\text{Nd}}$  vs. T(age) of dep. sherg. & nakhrites.

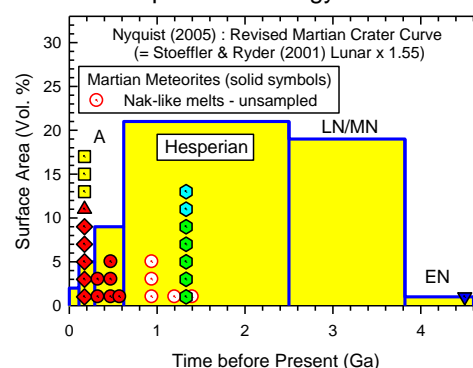


Figure 5. Age distributions of Martian Rocks.

**References:** [1] Irving A.J. et al. (2010) *LPS XXXI*, CD-ROM #1833. [2] Borg L. et al. (1997) *GCA* **61**, 4915–4931. [3] Borg L. et al. (2001) *LPS XXXII*, CD-ROM #1144. [4] Borg L. et al. (2003) *GCA* **67**, 3519–3536. [5] Shih C.-Y. et al. (2005) *Ant. Met. Res.* **18**, 46–65. [6] Shih C.-Y. et al. (2007) *LPS XXXVIII*, CD-ROM #1745. [7] Symes S.J.K. et al. (2008) *GCA* **72**, 1696–1710. [8] Nyquist L.E. et al. (2001) *Chronology and Evolution of Mars*, 105–164. Kluwer Academic Publ. Dordrecht/ Boston/London. [9] Ludwig K. (2003) Isoplot software package. [10] Harper C.L. Jr. et al. (1995) *Science* **267**, 213–217. [11] Jagoutz E. et al. (2000) *M&PS*. **35**, A83–84. [12] Lee D.C and Halliday A.N. (1997) *Nature* **388**, 854–857. [13] Foley C.N. et al. (2005) *GCA* **69**, 4557–4571. [14] Nyquist L.E. (2006) *Planetary Chronology Workshop* LPI Contr. No. 1320, CD-ROM #6010.